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Electrostatic Enhancement of Fabric Filtration of Fly Ash and Spray Dryer By-Product

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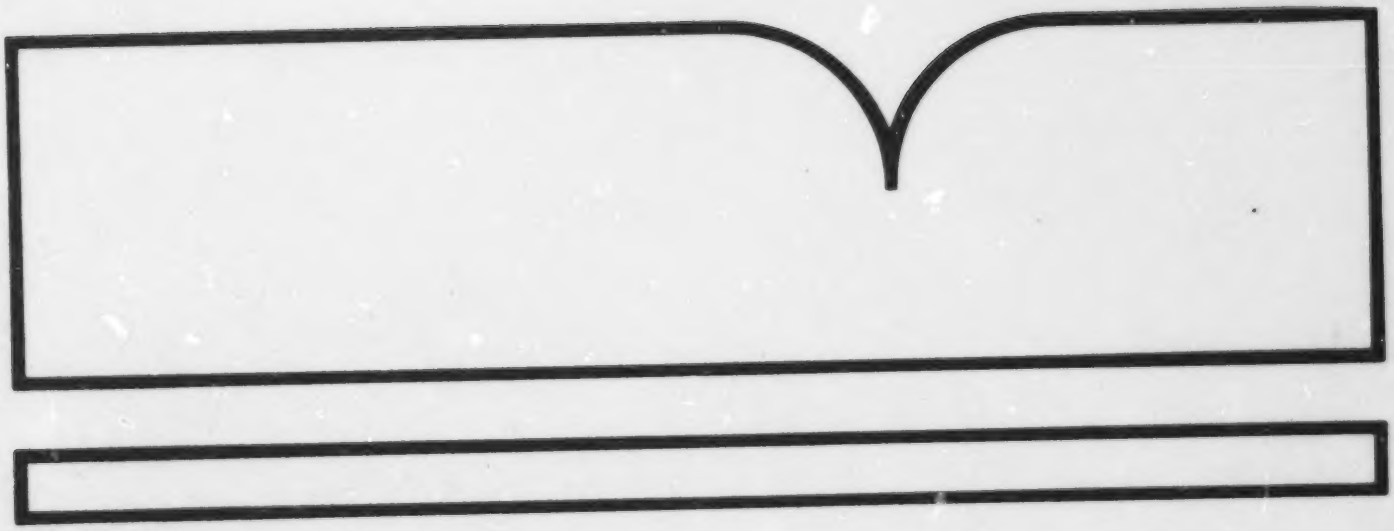

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ELECTROSTATIC ENHANCEMENT OF FABRIC FILTRATION OF FLY ASH AND SPRAY DRYER BY-PRODUCT

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16. ABSTRACT The paper describes small pilot-scale experiments, showing that the pressure drop increase during the fabric filtration of redispersed spray dryer by-product (chiefly calcium salts and fly ash) is significantly reduced by electrostatic enhancement of the filtration. The pressure drop rise for a typical electrostatically augmented fabric filtration (ESFF) is only 25% or less of that of the rise for a conventional filtration cycle. The ESFF takes advantage of the electrical characteristics of the spray dryer by-product, specifically the higher natural electrical charge, as compared to fly ash, and the relatively lower electrical resistivity of the spray dryer by-product at the high moisture and the low temperature conditions of filtration of spray dryer by-product. The low resistivity of the spray dryer by-product and certain fly ashes allows application of high corona voltages in the new Center-wire ESFF to produce an even slower pressure drop increase over the filtration cycle. Center-wire ESFF proved to be operable under conditions of high gas velocities and grain loadings which were beyond the range for successful conventional reverse-air fabric filtration. Results of tests on the Center-wire ESFF are presented and compared with conventional fabric filtration.

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Electrostatics	Stationary Sources	20C
Filtration	Fabric Filters	07D
Fabrics	Electrostatically Augmented Fabric Filtration	11E
Fly Ash		21B
Spray Drying	ESFF	07A, 13H

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ABSTRACT

Experiments conducted at small pilot scale show that the pressure drop increase during the fabric filtration of redispersed spray dryer by-product (chiefly calcium salts and fly ash) is significantly reduced through electrostatic enhancement of the filtration. The pressure drop rise for a typical electrostatically augmented fabric filtration (ESFF) is only one-fourth or less than that of the rise for a conventional filtration cycle. The ESFF takes advantage of the electrical characteristics of the spray dryer by-product, specifically the higher natural electrical charge, as compared to fly ash, and the relatively lower electrical resistivity of the spray dryer by-product at the high moisture and the low temperature conditions of filtration of spray dryer by-product. The low resistivity of the spray dryer by-product and certain fly ashes allows application of high corona voltages in the new Center-wire ESFF to produce even slower pressure drop increase over the filtration cycle. Center-wire ESFF proved to be operable under conditions of high gas velocities and grain loadings which were beyond the range for successful conventional reverse-air fabric filtration. Results of tests on the Center-wire ESFF are presented and compared with conventional fabric filtration.

ELECTROSTATIC ENHANCEMENT OF FABRIC FILTRATION OF FLY ASH AND SPRAY DRYER BY-PRODUCT

Louis S. Hovis, Bobby E. Daniel*
and Robert P. Donovan**

INTRODUCTION

At the first conference on electrostatic fabric filtration held in Princeton, New Jersey, in 1979, Lamb and his colleagues at the Textile Research Institute reported their investigations on an electric field enhancement of fabric filtration (1). The concept they reported was based on the creation of an electric field between parallel electrodes placed around the outside periphery of the filter bag. The concept, unlike most electrostatic enhancement schemes of that time, did not propose intentional charging of the particles. From late 1979 up through the present time, the EPA committed resources to the development of the practice which has been referred to as electrostatically enhanced fabric filtration (ESFF) in reports and technical papers. A number of sources give the details of that effort. On the basis of the detailed summary from Textile Research Institute (2), a pilot unit was established on an industrial boiler at a DuPont plant site in Waynesboro, Virginia. Both pulse-jet and reverse-air ESFF were shown to operate at the pilot scale, and the experiences were summarized in reports by VanOsdell, et al.(3), (4). The parallel field, with the electrodes near or on the surface of the bag, made especially good sense with pulse-jet cleaning when it became apparent that the pulse-jet support cage could be modified so that the vertical supports of the cage structure could be electrified with alternating polarity to produce the electric field shown in Figure 1. For reverse-air cleaning, the electrodes at the bag surface had to withstand the flexing of the reverse-air cycle. Conductive electrodes, consisting of strands of multiple fine stainless steel wires, were woven into a standard reverse-air fiberglass fabric, Figure 2.

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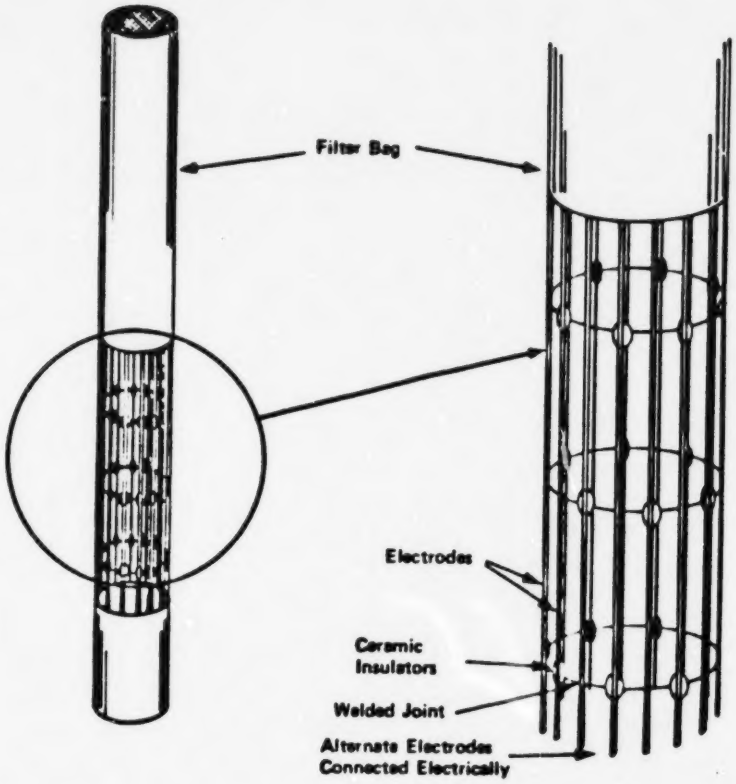

Figure 1. Inside electrodes utilizing insulators on cage rings.

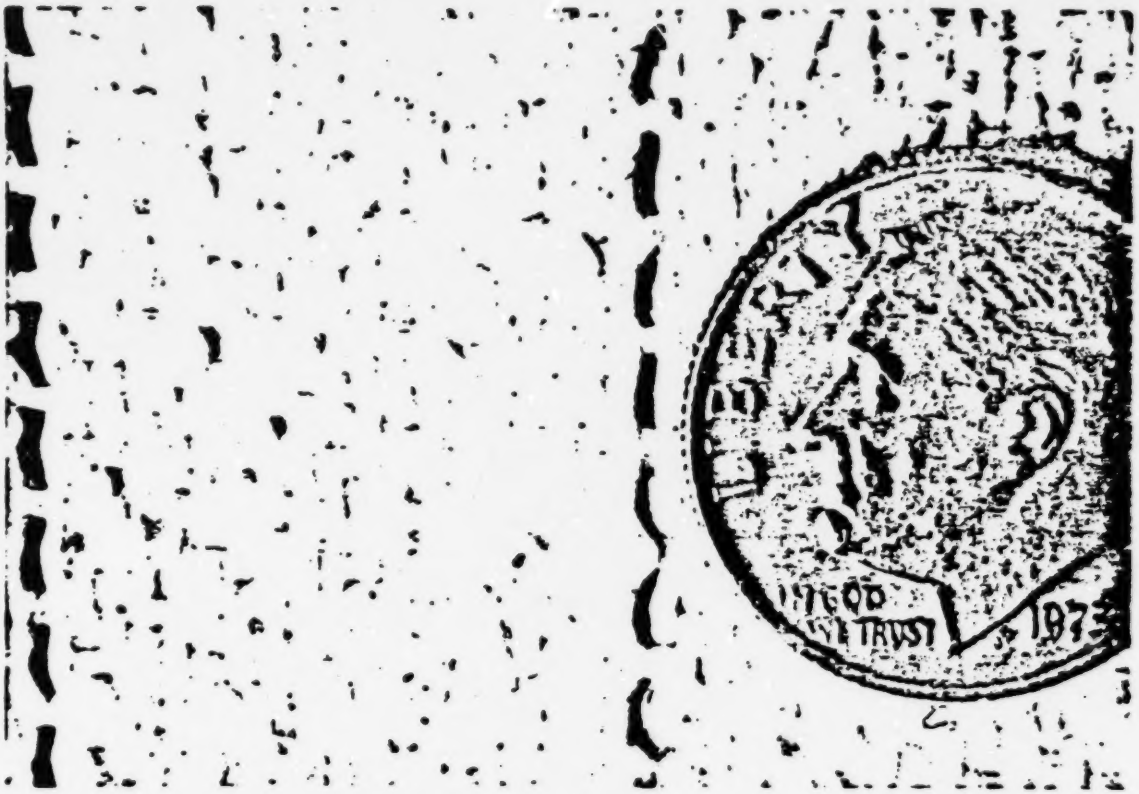

Figure 2. Fiberglass fabric showing woven-in electrodes.

When the woven-in conductors were connected to a power supply and a ground, alternately as in Figure 3, an electric field was created which fulfilled the concept of a parallel field.

The performance of ESFF was measured as the pressure drop ratio (PDR), the increase in pressure drop across the ESFF bag or baghouse during a filtering cycle divided by the increase for a similar conventional filtering cycle. The lower the PDR value, the greater is the ESFF effect. The PDR average for the Waynesboro pilot unit experiences averaged around 0.5. This PDR value was supported when a larger pilot unit ran for over a year at the Southwestern Public Service Harrington Station, Amarillo, Texas (5).

MECHANISM

From theoretical considerations and some efforts to model the mechanism, it was concluded that the only mechanism that could account for a 50% reduction in pressure drop (ΔP) rise during filtration was a non-uniform deposition of dust on the bag. Although a porous dust cake and collection on the upstream low-density region of the filter cloth could not be ruled out, their contributions to a small ΔP rise are considered marginal as compared to a non-uniform dust distribution (6). A non-uniform deposition attributable to Coulomb forces attracting naturally charged dust particles to the area of the electrodes on the bag surface could be modeled. Experimental evidence for the non-uniform deposition was observed on the EPA in-house pilot pulse-jet unit when the grain loading was increased to match industry practice in the filtration of spray dryer by-product. As seen in Figure 4, the loading of dust on the outside of the bag was heaviest along the electrodes. The role of natural charge was also in evidence in this experiment. The low PDR of 0.2 was in part attributable to a relatively high positive charge of the dust, noted as Riverside spray dryer by-product in Table 1. ESFF plus precharging experiments carried out by Lamb (7), in which the ESFF effect was remarkably enhanced because the additional charge caused a major increase in Coulomb attraction along the electrodes, reinforced the non-uniform deposition model. There was a correspondingly low ΔP rise. On opening the bag it was clearly revealed that dust had collected along the electrodes, mostly in the bottom half of the bag.

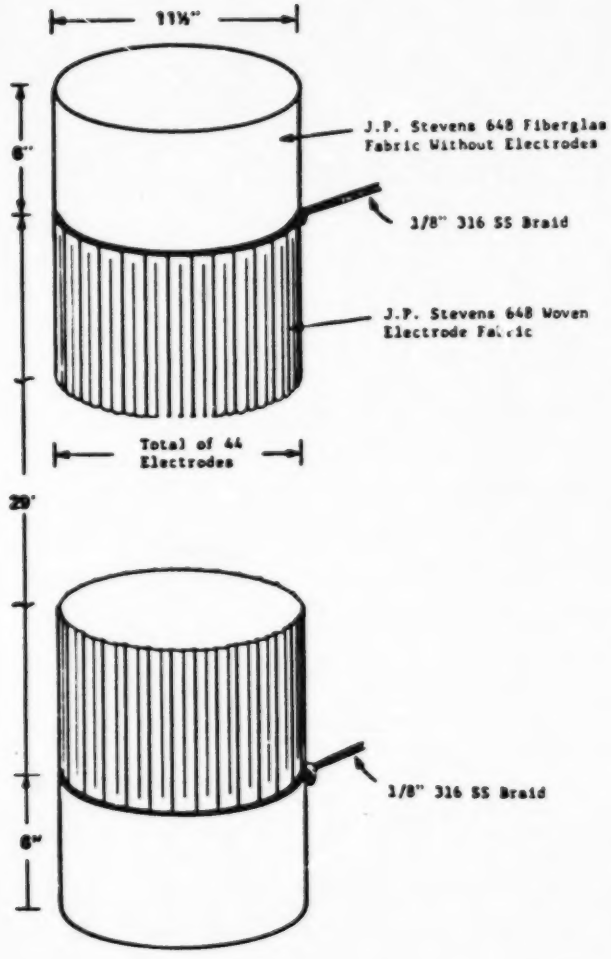

Figure 3. Construction of the woven-electrode bags.

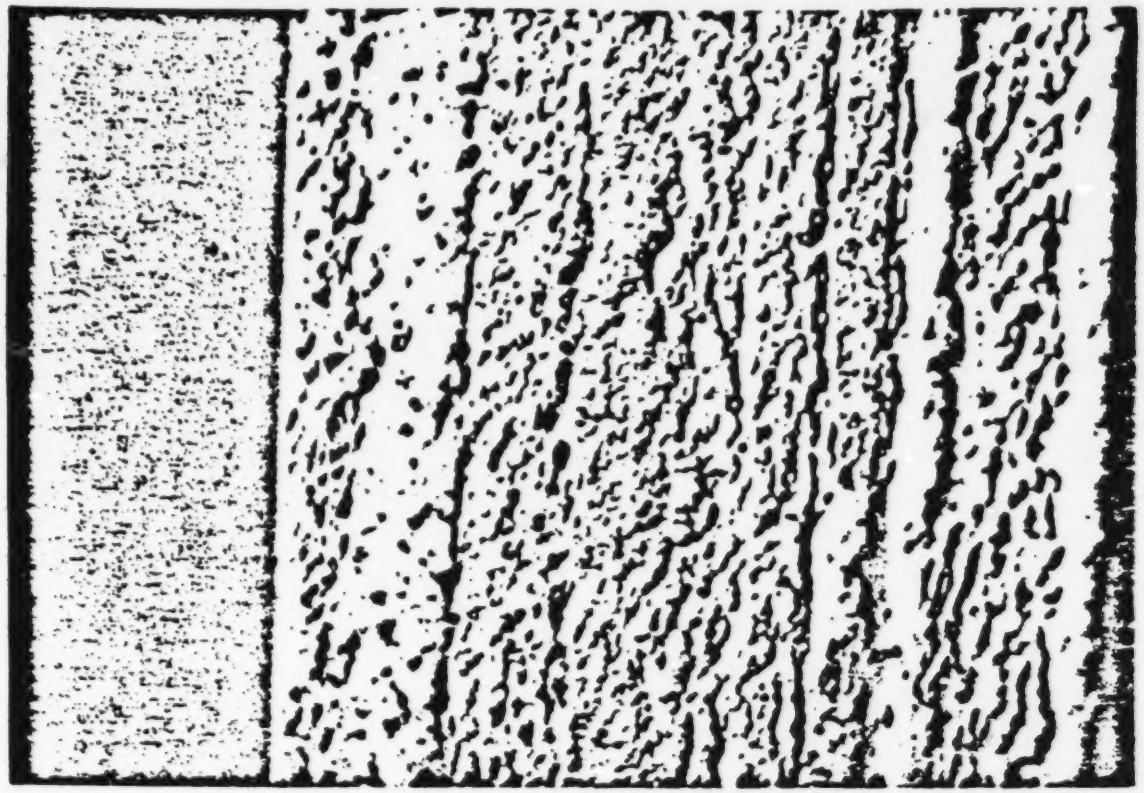

Figure 4. Spray dryer by-product deposit on electrified bag (pulse-jet cleaning).

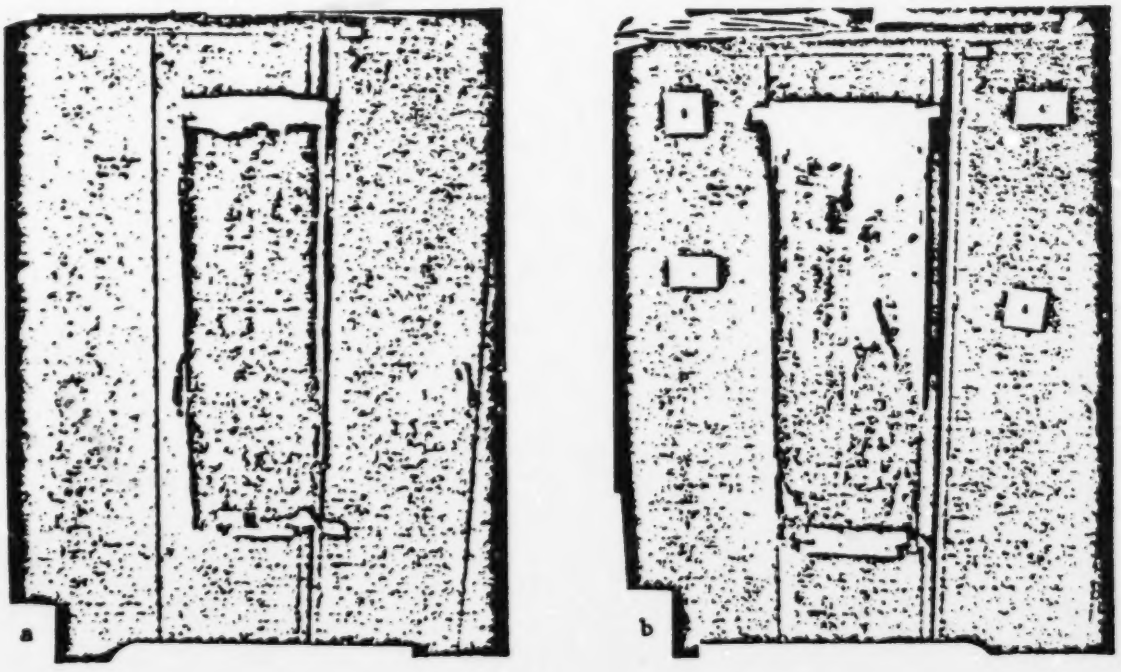

Figure 5. Dust deposition during filtration:
(a) conventional, and (b) Super ESFF.

Table 1. REDISPERSED DUST CHARGE-TO-MASS RATIO

Dust	μc/g
Detroit Edison fly ash:	- 0.28
Southwestern Public Service fly ash:	+ 0.25
Riverside spray dryer by-product:	+ 1.68
Antelope Valley spray dryer by-product:	+ 0.36
University of Tennessee spray dryer by-product:	+ 0.26
	+ 0.6*
Platte River spray dryer by-product:	+ 0.26

*Measurement made in the U.T. unit.

Table 2. FABRIC, DUST RESISTIVITIES
(ohm-cm)

Temp °F:	300	300	160	160
% H_2O	5	10	5	10
Stevens 648, clean	3×10^{13}	5×10^{12}	2×10^{13}	
Stevens 648, dirty	6×10^{12}	10^{12}	6×10^{12}	
SPS, Harrington	10^{11}	3×10^{10}		4×10^{8}
Detroit Edison	10^{12}			
Riverside	10^{13}		2×10^{9}	10^{8}
Antelope Valley			10^{8}	10^{7}

CENTER-WIRE ELECTROSTATIC ENHANCEMENT OF FABRIC FILTRATION (SUPER ESFF)

The concept of Super ESFF originated from experiments carried out to exploit the aforementioned observations. The original idea was to provide for corona charging inside the bag by way of a central electrode with the expectation that the charged particles would deposit along grounded electrodes (braided grounding straps) sewn to the inside surface of the bag. The bag was opened after a cleaning cycle to reveal that there was selective deposition, but the deposits were not so much along the electrodes as it was almost entirely in the lower half of the bag. After that the sewn-on electrodes were replaced by a metal screen on the outside of the bag to serve as the ground side of the electric field with the center electrode. The opened bag showed a pattern of dust collection on the lower part of the bag with power on and complete coverage with power off as shown in Figure 5.

A description of the Super ESFF experiment would include a 1/8-in. steel wire in the center of the bag electrically isolated from the baghouse structure. High voltage was applied to the wire to produce an electric field of 2-3 kV/cm between the wire and the grounded conductors on the bag surface. To obtain an electric field of this magnitude, the applied voltage produced a corona discharge, with the potential for charging the particles. A preliminary modeling effort and subsequent experimental evidence indicated that the charged particles are acted on by the electric field (perpendicular to the bag) and forced out of the gas streamlines and toward the bag surface. The net result is that the particles deposit on the bag closer to the bag inlet than it would otherwise with no perpendicular electric field acting. A thicker dust layer at the bottom leaves a relatively dust free area of fabric at the top of the bag for easy passage of gas. This results in a significantly lower increase in ΔP during the filtration cycle.

The effectiveness of Super ESFF depends upon those variables which cause the particles to deviate from the path; e.g., those variables which affect either the vertical or horizontal component of the particle trajectory. At some point, the model should have the reliability so that the pressure drop or other experimental result can be predicted. For now, direct experimentation is relied upon to give evidence of Super ESFF effects. In actual laboratory practice, the evidence for Super ESFF is conveniently revealed in a ΔP vs time sequence taken directly from the laboratory controller/recorder. The

effect of turning power on and off can be shown on the ΔP control strip charts. With power on to the point of an ionizing voltage, the distribution of dust at the bottom of the bag allows a small ΔP increase with time. With power off the ΔP climbs much higher. Figures 6, 7, and 8 are taken directly from the recorder charts. The recorder-generated graphs show the remarkably low ΔP for power on and the rapid change in slope of ΔP when the power is turned either off or on. The rapid recovery of the ESFF effect is of special significance in actual practice. Two types of dusts are represented in these graphs, and filtration in each case was carried out under conditions that simulate actual practice. Spray dryer by-product is filtered at low temperature, high moisture, and high grain loading. The PDR from Figures 6 and 7 is only about 0.1. In Figure 8 the dust was typical stoker fly ash, but the grain loading in the experiment was higher than typical stoker operation. The PDR value from Figure 8 is approximately 0.2. Other fly ashes tested in Super ESFF were similar with PDRs averaging up to 0.3.

Dust and Fabric Properties

Differences in ESFF effect are attributable to filtration conditions and to the properties of the dust and the fabric. Electrical resistivities of the dust and fabric have a governing role in electrical enhancement. The importance of resistivity can be illustrated for spray dry by-product. Figure 9 shows the resistivity of several dusts, including the spray dryer by-product, as functions of temperature and moisture. The spray dryer by-product has an especially high resistivity at 300°F (149°C), the temperature at which fly ash is typically filtered. At this temperature the filtration of the by-product could not be significantly improved by ESFF. Only when the temperature was lowered and the moisture increased was the PDR lowered to the representative values that are reported. The low PDRs corresponded to low resistivities. Subseqent experiments indicated that the lower the resistivity for a given fly ash, the higher the voltage that can be obtained and the greater the ESFF effect. Table 2 lists resistivities of dusts and fabrics under several conditions of moisture and temperature. Ordinarily the fabric has a higher resistivity than the fly ash, and the fabric cannot be altered as readily with moisture addition or lower temperature. In a few cases where the resistivity of the dust is very low (e.g., stoker-fired boiler fly ash), it may be possible to merely coat the inside of the bag to decrease resistivity to the point that a sufficient current can be maintained for charging the entering particles and provide lower potential for an electric field.

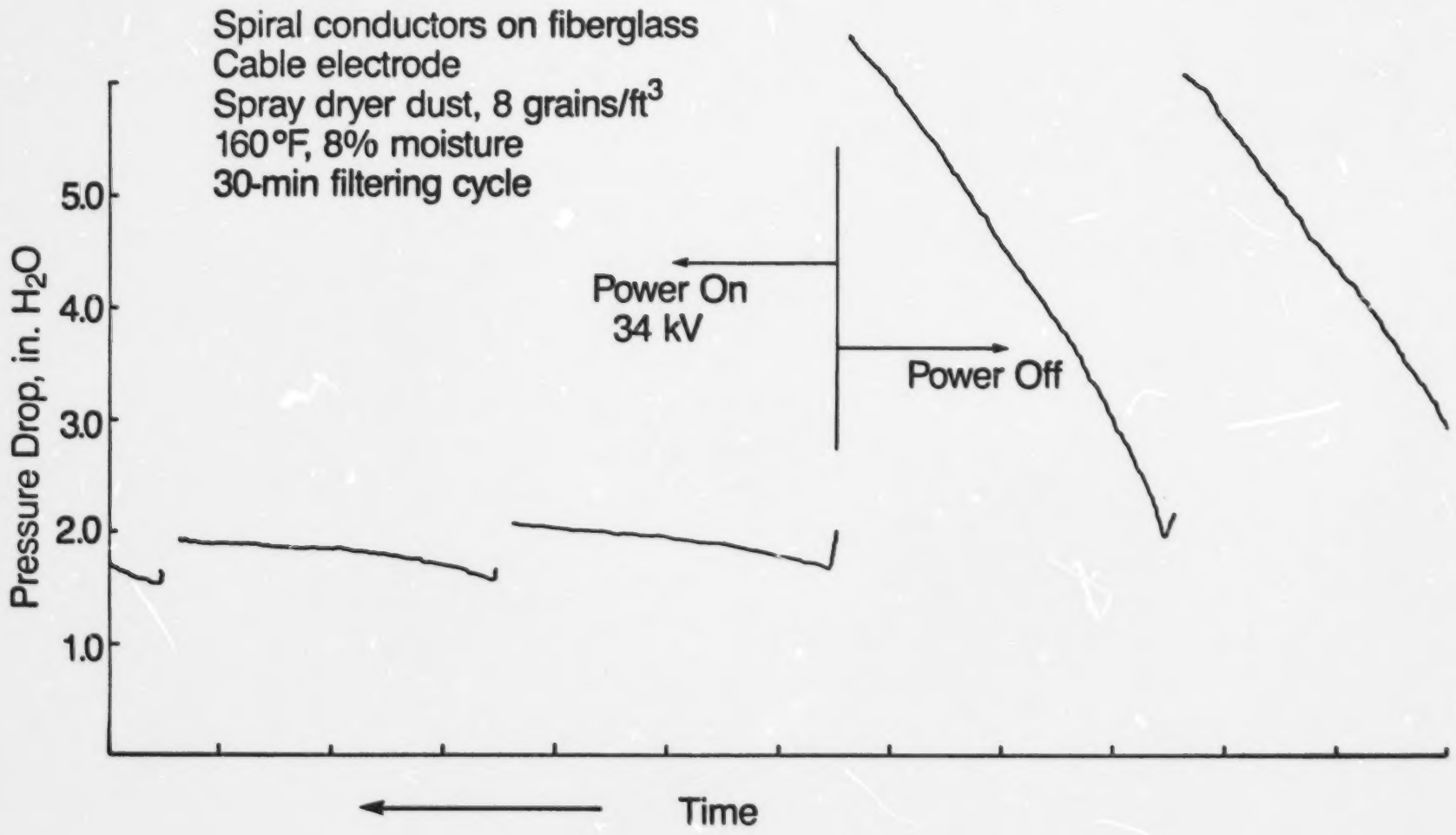

Figure 6. Super ESFF, showing power-on effect.

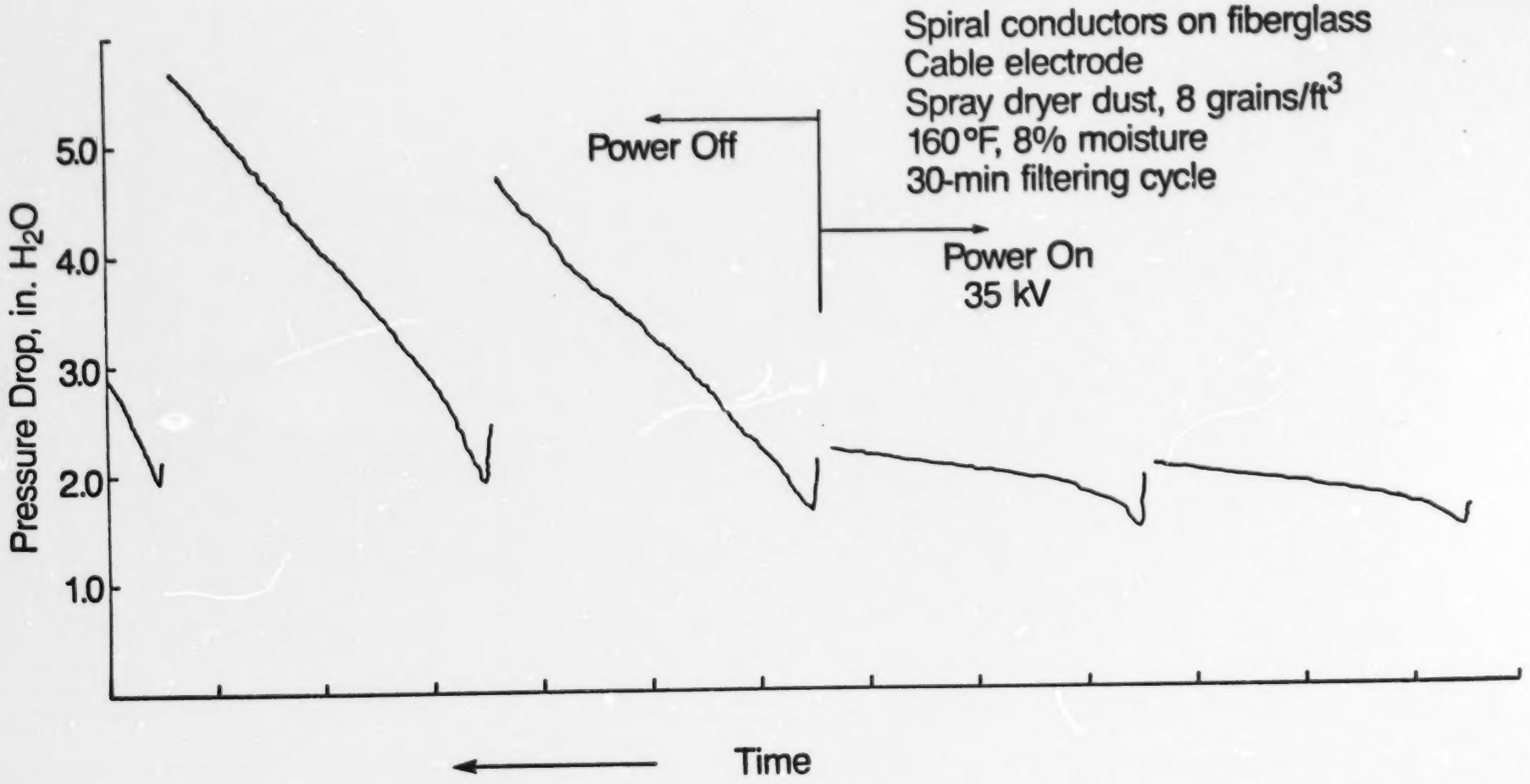

Figure 7. Super ESFF, showing power-off effect.

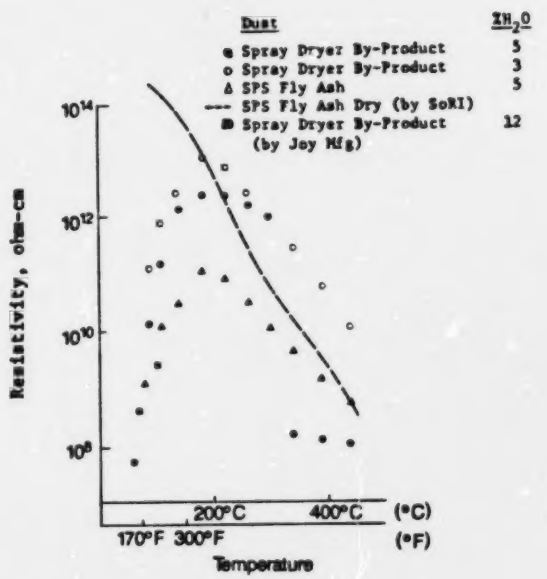

Figure 9. Fly Ash electrical resistivity.

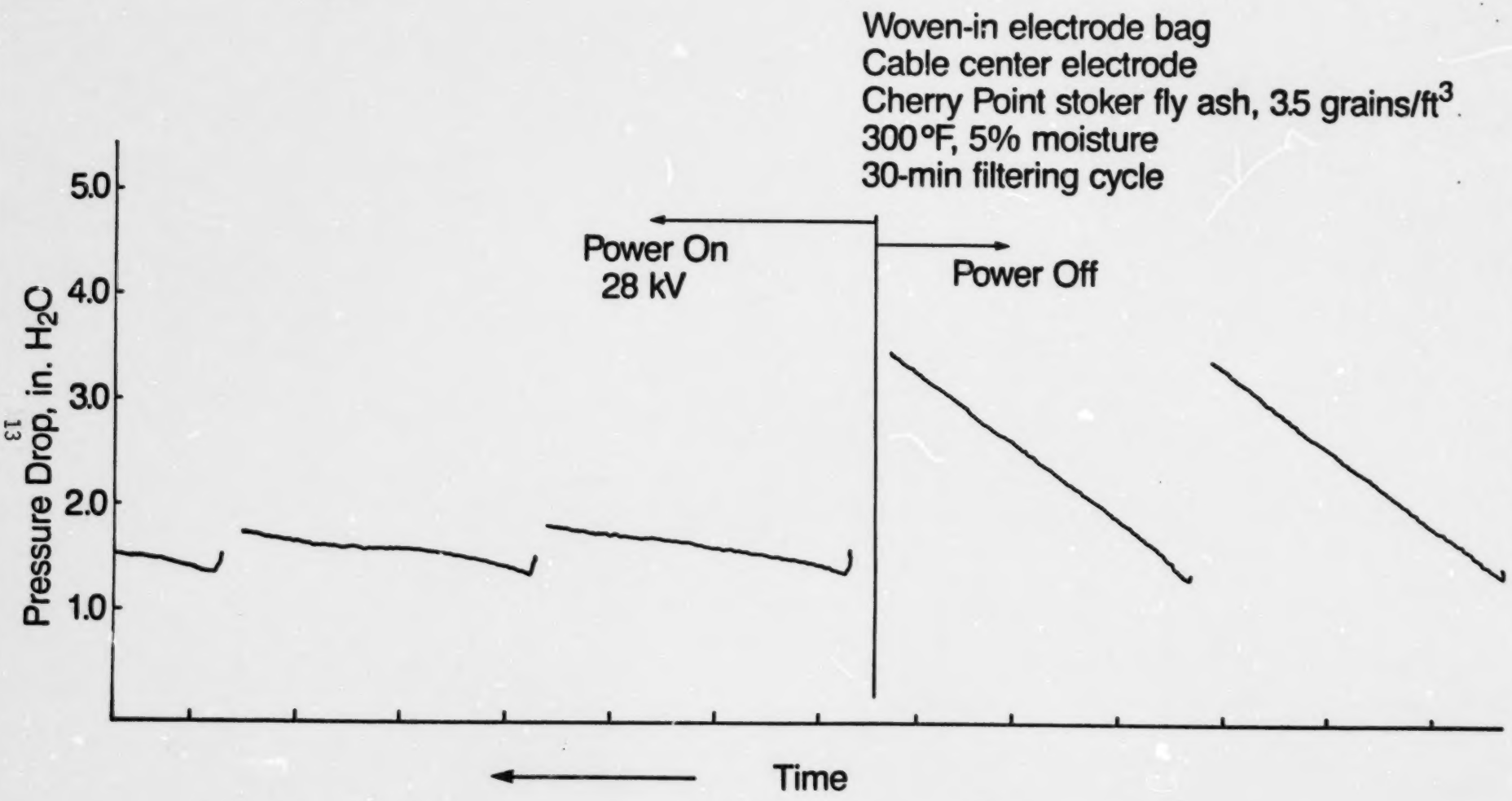

Figure 8. Effect of Super ESFF on stoker fly ash.

A Super ESFF pilot baghouse on a 77,000 lb/hr stoker boiler is effectively collecting stoker fly ash on a conventional filter fabric. The remarkable quality of the stoker fly ash is that an electric field can be sustained even in the face of the high carbon content and high conductivity of the ash. Special connectors hold the center wire in place without a buildup of dust on the structure to cause bridging and breakdown (sparking) between center wire and bag.

Conductive Bags and Center Electrode

For the greatest Super ESFF effect when filtering fly ash and spray dryer by-product, it is necessary to have a conductive bag or to locate grounded conductors in the vicinity of the bag surface to ensure a strong electric field between center wire and bag. It became apparent that one solution was to make the bag conductive with woven-in or sewn-on conductors. A number of center-wire grounded surfaces were tested as listed in Table 3. The fiberglass fabric with conductive stainless steel filaments woven-in, listed in the table, is the same J.P. Stevens fabric developed for the parallel field (conventional) ESFF (8). This fabric was used in many of the experiments because it was available, and it still appears to be a practical solution. The number of woven wires could be reduced which would correspondingly reduce the cost of the fabric. A Duratex No-Shock knitted bag, obtained from Menardi Southern, performed well at the lower temperatures. The bag with a spiral-wound wire attached to the surface would be the simplest of all to fabricate since the fabric is not involved in making the conductive element.

Specification of an economically feasible conductive bag for Super ESFF is a problem which has not been completely solved. Because the difficulties in weaving have been overcome, it has been estimated that woven-in electrode fiberglass bags could be fabricated essentially for the additional cost of the metal fibers (8). The cost of the bag would then decrease with the quantity of wire used. However, the lower limit on the electrode density has not been determined.

The shape and construction of the center electrode was also investigated for ESFF effect and for a more practical electrode system. Table 4 lists the electrodes that were considered. A two-section configuration with different diameter wires worked well, and the 1/8-in. flexible steel cable solved the

Table 3. "CONDUCTIVE " BAG SURFACES

Stevens 648/wire mesh wrapped outside
Stevens 648/dust layer
Stevens 648/woven-in conductors
Stevens 648/parallel spiral conductors attached to surface
Duratex "No Shock" knit

Table 4. TYPES OF ELECTRODES EVALUATED

1/8-in. Solid wire
Step down 3/16 - 1/8-in.
1/4-in. Wire--4 barbs at bottom
1/8-in. Flexible cable

problem of stringing a long wire in a commercial size bag. The cable produced a uniform corona and performed well in actual practice.

Maximizing Particle Charge

Figure 10 shows the Super ESFF effect as a function of moisture at a fixed temperature. This in essence is the effect of moisture and temperature on electrical resistivity. A lower resistivity fly ash, no matter how it is accomplished, permits a higher voltage and higher current without back corona. When back corona occurs, the limit of the voltage has been reached, and unless the back corona is quenched, the ionizing center-wire voltage and the ESFF effect are suppressed.

The effect of field strength and corona voltage can be seen in Figure 11. At a given moisture level and temperature which fixes the resistivity, the greater the voltage, the greater will be the ESFF effect. In a stoker fly ash sample, for example, the ESFF/PDR was 0.35 at 21 kV and 300°F with 5.5% water. On increasing to 27 kV, the PDR dropped to < 0.2 and to < 0.15 when the voltage was controlled at 28 kV. Of course the electrical current varied with the higher current corresponding to the higher voltages. The stoker fly ash represents a low resistivity fly ash because of the high carbon content (25% or greater).

The degree of charging of particles depends on the voltage obtainable or the current which can be maintained without the onset of back corona. Therefore when we discuss the essence of why some fly ashes or products have a higher PDR than others, it could be thought of in terms of the amount of charging. For example, Detroit Edison dust has a high resistivity at 300°F and low moisture. It is likely that very little charging can occur under these conditions, and the electric field acts on the natural charges of particles. Under these circumstances a real but unknown portion of the pressure drop reduction (due to deposition on the lower half of the bag) is due to natural charge much as it is in conventional ESFF.

FUTURE WORK

Research is required to complete the model and to pick optimum electrical and flow conditions. Figure 12 shows the schematic of a proposed commercial system. Commercial development probably depends more on the definition of a

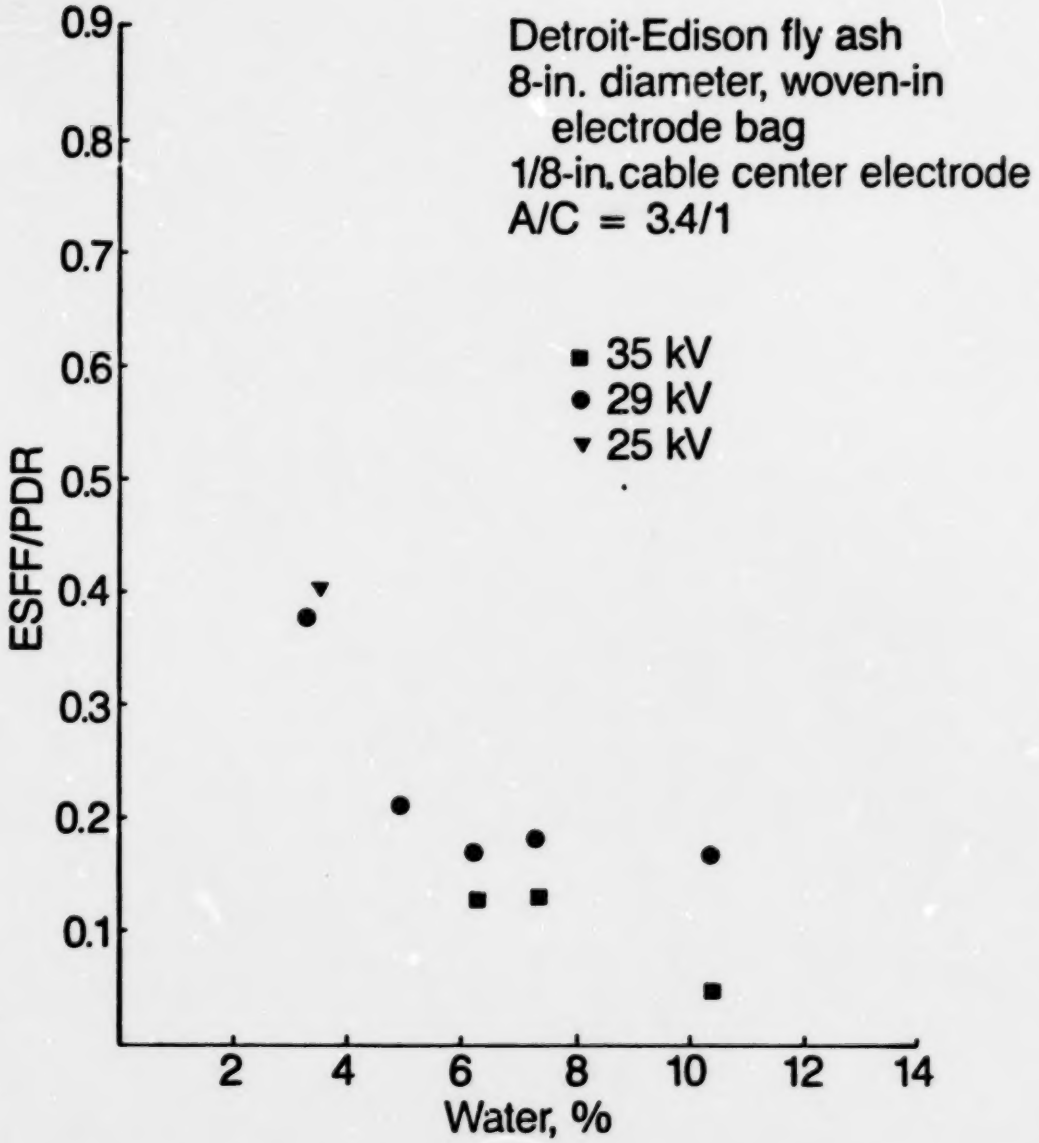

Figure 10. Effect of moisture on Super ESFF at 300°F.

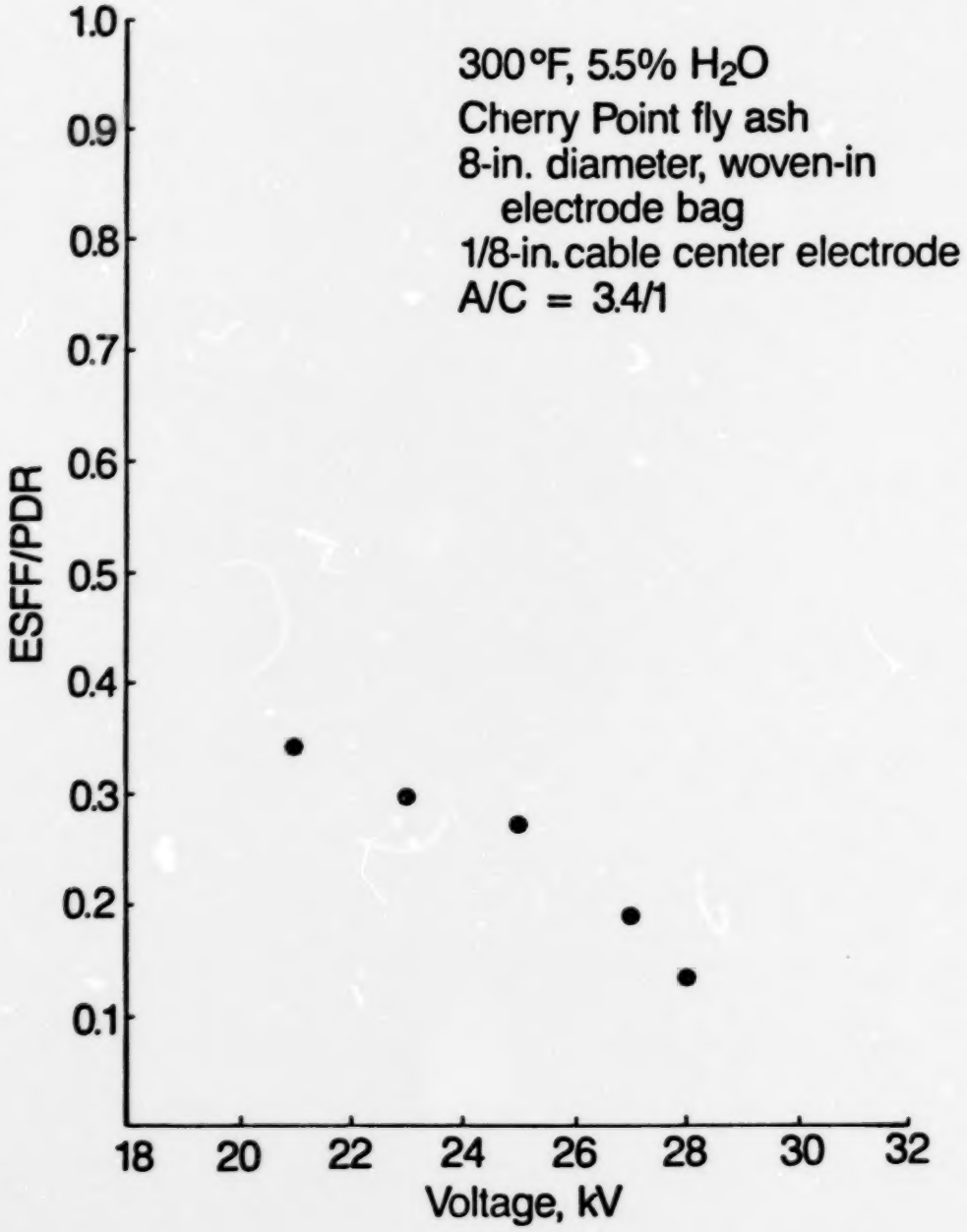

Figure 11. Effect of applied voltage on Super ESFF.

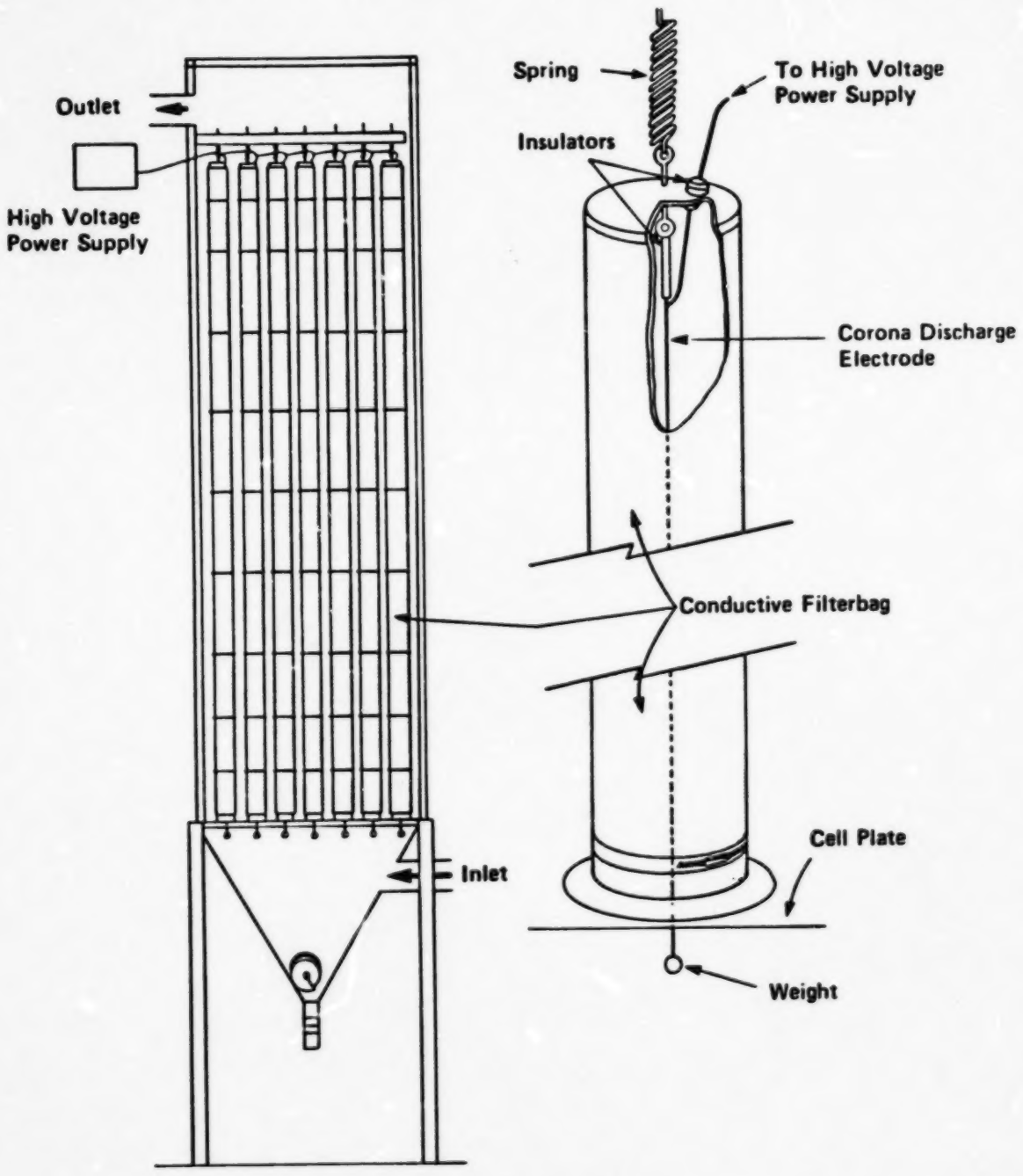

Figure 12. Super ESFF reverse-air configuration.

suitable conductive fabric and some proof of stability of the system over an extended time period. Work now underway in pilot units on stoker and pulverized coal systems is expected to offer some answers to the latter. The conductive fabric problem has not been resolved although some likely candidate fabrics have been tested.

Work has been initiated on a new electrostatic baghouse arrangment to make use of the non-uniform dust deposition concept in a pulse-jet system. When described the electrode configuration appears to be the simplest ESFF system. As shown in the schematic diagram, Figure 13, electrodes on the outside of the bags provide for corona charging and an electric field in combination with the grounded cages inside the bags. The field is more intense over some parts of the bag, and it is expected that the variation in field strength should give a variation in particle deposition.

CONCLUSIONS

Laboratory investigations of Super ESFF indicate that, if the technology can be successfully transferred to the field, there is an excellent potential for reducing cost of fabric filtration. To ensure success a long term pilot run and a suitable fabric acceptable in the industry must be established. Assuming these goals can be reached, it appears likely that Super ESFF baghouses can operate at pressure drops that increase during the filtration cycle only 10 to 30% of the expected increase during conventional filtration. Performance is expected to differ from site to site because of differences in the coal burned and the conditions under which the fly ash is collected.

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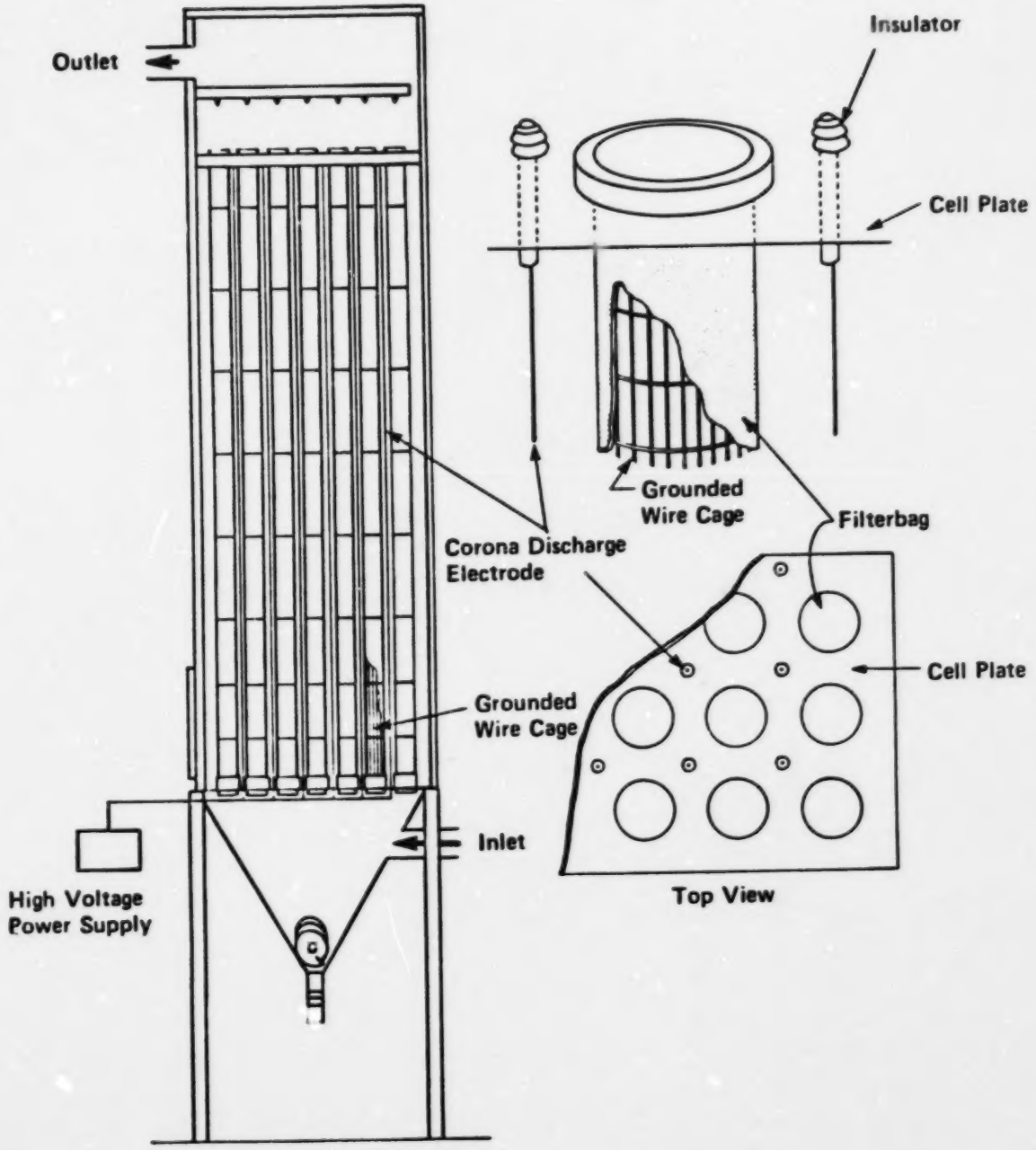

Figure 13. Super ESFF pulse-jet configuration.

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METRIC EQUIVALENTS

Readers more familiar with metric units may use the following to convert to that system:

Nonmetric	Multiply by	Yields metric
in. H_2O	249	Pa
in.	0.0254	m
gr/ft^3	1.2	g/m^3
°F	(°F-32) x 0.56	°C
ft	0.305	m
ft^3	28.3	L
lb	0.454	kg